# GEWEX water vapor assessment plan

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**Table of Contents**

## 1 Purpose of document

The assessment plan recalls the GEWEX Water Vapor Assessment (G-VAP) scope and states the GEWEX needs on water vapour data records. The main part of the plan comprises of scientific questions and of scientific activities which are needed to answer these questions and to characterise the water vapour data records and their utility for the user community. The plan assigns responsible persons to each activity. It also defines the expected outcome, governance and data policy.
It does not intend to be a fully developed project plan to ensure the necessary flexibility to cope with changing funding situations, with changing personnel and with interim results.

***We strongly encourage the scientific community to contribute to G-VAP!***

***Please contact the co-chairs and activity leaders when you want to contribute with your data record, to one of the listed activities or when you want to contribute with a new activity!***

Document history:

| Version | Author(s) | Description | Date |
|---|---|---|---|
| V1.0 | M. Schröder (DWD) | Distributed to G-VAP list | 05 June 2013 |
| V1.1 | M. Schröder (DWD) | Feedback implemented | 17 July 2013 |
| V2.0, draft | M. Schröder (DWD) | First draft for G-VAP's second phase | 05 November 2018 |
| V2.0 | M. Schröder (DWD) | Feedback implemented | 19 November 2018 |

## 2 G-VAP scope

The need for quality assessments of Essential Climate Variables (ECVs) Climate Data Records (CDRs) is part of the GCOS guidelines for the generation of data products. The assessement process shall give an overview of available data records and enable users to judge the quality and fitness for purpose of CDRs by informing them about the strengths and weaknesses of existing and readily available records. This is achieved by inter-comparison and evaluation, also to, if possible, provide reasons for differences and limitations. Assessments of data records related to the global energy and water cycles became an integral part of GEWEX activities over the last decades.

The GEWEX Radiation Panel (GRP, now called the GEWEX Data and Analysis Panel - GDAP) has initiated a Water Vapor Assessment in 2011, further on referred to as G-VAP. The major purpose of G-VAP is to[1]:

[1] http://www.gewex.org/gewexnews/May2011.pdf

- Quantify the current state of the art in water vapour products being constructed for climate applications, and by this;
- Support the selection process of suitable water vapour products by GDAP for its production of globally consistent water and energy cycle products.

The optimum GEWEX needs on satellite based temperature and humidity products are:

- Global coverage,
- 3 hourly temporal resolution,
- 10 km spatial resolution,
- Availability from 1979 to present,
- Verified high quality (uncertainty and in particular temporal stability).

While the requirements on resolution are similar between GCOS-200 and the GEWEX needs, G-VAP will consider the GCOS requirements on accuracy and stability as baseline guidance. The assessment of atmospheric profiles (specific humidity preferred) is of highest interest to GDAP as such profiles are the input to the GEWEX products (see www.gewex.org for an overview). The usage of the products within GDAP activities essentially implies to study long-term data records.

G-VAP activities started in 2011. A first workshop was hosted in March 2011 by the European Space Agency's European Space Research Institute (ESA-ESRIN) with support from the ESA DUE GlobVapour project and the second workshop was hosted in September 2012 by Deutscher Wetterdienst (DWD) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Satellite Application Facility on Climate Monitoring (CM SAF). The results of these workshops together with feedback from GDAP led to the definition of the scope of G-VAP as outlined in the first assessment plan (available at https://gewex-vap.org). G-VAP's first phase ended with the publication of the WCRP report on G-VAP (WCRP, 2017). For G-VAP's second phase the overall scope is still applicable and was further refined based on discussions at the 7th G-VAP workshop in October 2017, hosted by the National Centre for Earth Observation at the University of Leicester:

- All three products defined by GCOS to represent the ECV water vapour are considered (see e.g. GCOS-200):
  - Total column water vapour (TCWV),
  - Tropospheric and lower-stratospheric profiles of water vapour (WV) and their related temperature products,
  - Upper tropospheric humidity (UTH).

  G-VAP does not include sea/land surface temperature or 2m temperature/humidity unless these are integral parts of the water vapour profile;
- In principle G-VAP considers all data records that are longer than approximately ten years. The assessment will also consider data records that may not be used as input for GEWEX water and energy cycle data sets but which are important to establish a deeper understanding of atmospheric water vapour observations. This will considerably increase the number of data records that can be analysed;

- Data records with a temporal coverage of more than 25 years and a start in the late 1980s are considered long-term while the common period of all data records defines the temporal coverage of the data records in the short-term category of the G-VAP data archive.
- The assessment considers data records that are provided by assessment participants, that are readily and freely available and well documented;
- The assessment focuses on overall characteristics of participating satellite data records and reanalysis as determined from inter-comparisons, comparisons against in situ observations and ground-based products and consistently applied analysis;
- Long-term Level-3 (gridded products) products are analysed on different time and space scales in order to get an overview of issues in Level-3 products. These issues can then be studied in more detail using Level-2 and/or Level-1 data and by dedicated Level-2 data comparisons employing high quality satellite and ground-based observations;
- Intercomparisons and analysis at regions/periods of distinct quality and/or characterised by consistent atmospheric conditions (e.g., stratocumulus regions, Arctic,...) are carried out to assess the quality of the data records.
- Uncertainty information of water vapour data records will be assessed when available.
- Recommendations defined in WCRP (2017) will be addressed to the maximum extent possible. The recommendations are given in the Appendix.
- No quality ranking of the assessed data records is attempted.
- G-VAP pursues information exchange with the Stratosphere-troposphere Processes And their Role in Climate (SPARC) water vapour activity, with SPARC focusing on the stratosphere and G-VAP focusing on the troposphere.

## 3 Main questions for satellite data record evaluation

Following presentations and discussions at the first GDAP meeting in October 2012 key questions for the evaluation of data records have been formulated. In view of results from G-VAP's first phase and consensus results from the 7$^{th}$ G-VAP workshop the science questions have been slightly adapted and determine the metric to identify strengths and limitations, to analyse differences and to find reasons for distinct differences and limitations.
The *science* questions are:

Q1)

a) How large are the differences in observed temporal changes in long-term satellite data records of water vapour on global and regional scales?
b) Are the observed temporal changes and anomalies, on global and regional scale, in line with theoretical expectations?
c) Are the differences in observed temporal changes within uncertainty limits?
d) What is the degree of homogeneity (break points) and stability of each long-term satellite data record?

Q2) What is the degree of consistency among the products, i.e., are the differences between data records within uncertainties estimates?

Q3)

a) Do the satellite data records exhibit areas of distinct quality and how can the distinct differences and limitations be explained?
b) What is the quality of long-term satellite WV products in the lowermost part of the atmosphere and in the upper troposphere?
c) What is the quality of long-term satellite TCWV and WV products over areas where ground-based and in-situ observations are rarely available, e.g. over oceans, here in particular over the stratocumulus regions and over, e.g., the Arctic?

Q4) What are the differences in quality between satellite products and products from reanalysis and are the observed differences significant?

The *technical* question is:
Q5) How easily can the satellite data records be downloaded, read and understood?

## 4 Technical implementation

**The technical implementation is outlined in**

Table 1. These activities are needed for management and organisation and to set up the basis for scientific activities (next section).

**Table 1: Overview of technical activities together with team members (underlined: responsible person).**

| Theme | Activity | Team | Comment | Until |
|---|---|---|---|---|
| Data base, input data | Collect satellite data records with focus on Level-3 (gridded) data records, i.e., update G-VAP data archive.<br>Collect data needed for scientific activities. | M. Schröder, responsible persons of activities | | Q3 2020 |
| Scientific tools | Develop/update analysis tools. | Responsible person of activities | | 2020 |
| Outreach | Maintain G-VAP webpage. | Co-chairs, F. Fell | | Cont'd |
| Outreach | Showcase the benefit/need of diurnal cycle sampling at global scales by GPS RO for NWP, climate analysis and others. | UCAR, SSE, and IROWG | Literature review, potentially dedicated analysis | Cont'd, fall 2020 |
| Outreach | Liaise between SPARC, G-VAP and CCI. | M. Schröder, E. R. Kursinski | include W. Read and M. Hegglin in | Cont'd |

| Theme | Activity | Team | Comment | Until |
|---|---|---|---|---|
| | | | the loop | |
| Outreach | Establish link to IROWG. | E. R. Kursinski, J. Nielsen, S.-P. Ho | | Cont'd |
| Outreach | Establish link to GEWEX PROES on UTCC. | J. Luo, M. Schröder | | Cont'd |
| Workshops | Organise and carry out workshops and teleconferences. | Co-chairs | | Cont'd |
| Reporting | Report to GDAP and summarise final G-VAP results in WCRP report. | Co-chairs, team leaders | | Cont'd, late 2020/early 2020 |

## 5 Scientific activities

Table 2 provides an overview of scientific activities which are carried out in order to address the G-VAP scope, to find answers to the G-VAP questions (section 3), to reveal agreements/strengths and differences/limitations among/of the data records. Finally, the objective is to find explanations for the observed differences/limitations.

**Table 2: Overview of scientific activities together with responsible person (underlined) and contributing partners. All activities are based on G-VAP recommendations and have been consensus at the 7th G-VAP workshop.**

| Theme | Activity | Team | Comment | Until |
|---|---|---|---|---|
| Intercompa-rison, analysis | Continue<br>• intercomparisons,<br>• stability/homogeneity analysis,<br>• trend estimation,<br>• estimating the response to SST,<br>• refined analysis in regions of distinct features in above results<br>for TCWV and profiles using existing G-VAP tools and updated data records, focus on gridded monthly data. | M. Schröder, N. N. | Potentially refine analysis by considering redefined regions | Cont'd, fall 2020 |
| Intercompa-rison | Continue intercomparison and quality analysis of UTH products. | L. Shi, M. Schröder | | Cont'd, fall 2020 |
| Validation, analysis | Assess quality and carry out intercomparisons and analysis at regions and periods characterised by consistent atmospheric conditions (e.g., subsidence | | | |

| Theme | Activity | Team | Comment | Until |
|---|---|---|---|---|
| | regions, stratocumulus regions, Arctic,...):<br><br>Analyse quality of profile data records over stratocumulus regions using GPS RO (and potentially other) as reference and including filtering of super retraction in GPS RO data. | S.-P. Ho,<br>R. Kursinski,<br>M. Schröder | | Cont'd, fall 2020 |
| | Discuss and potentially carry out joint UTCC/G-VAP analysis of upper tropospheric humidity in vicinity of deep convection and anvil clouds. | J. Luo,<br>M. Schröder,<br>H. Brogniez | consider using data from ARM Azores station | Cont'd, fall 2020 |
| | Analyse FTH variability in subsiding regions & compare to GPS-RO. Focus on the higher moments of the PDFs. | L. Picon,<br>H. Brogniez,<br>M. Schröder | consider the use of MW estimates of UTH | Cont'd, fall 2020 |
| | Assessment of water vapour from satellite and reanalysis in the Arctic. | S. Crewell,<br>A. Radovan,<br>M. Schröder | | 2019 |
| Validation | Assess quality at near surface layers and in the upper troposphere using high quality ground-based and in-situ observations such as GRUAN (each as Level 2) | A. Reale (NOAA),<br>T. Trent (U. Leicester),<br>M. Schröder (DWD) | | Cont'd, fall 2020 |
| Validation | Intercompare water vapour profile data records at certain pressure levels using PDF analysis and instantaneous data | E. R. Kursinski | Include 326 hPa to provide support to MLS and wider UTLS community | Cont'd, fall 2020 |
| Validation | Assess and potentially achieve consistency between reference observations | X. Calbet,<br>R. Preusker,<br>T. Trent,<br>M. Schröder | Consistency between CrIS, OLCI and GRUAN; estimation of collocation uncertainty, | Cont'd, fall 2020 |

| Theme | Activity | Team | Comment | Until |
|---|---|---|---|---|
| | | | uncertainties from radiative transfer | |
| Validation | Assess and potentially characterise the difference between observations in all-sky and cloudy-sky observations | S.-P. Ho, M. Schröder | | Cont'd, fall 2020 |
| Analysis | Approach characterisation of the clear-sky bias by taking into account the diurnal cycle of clouds | U. Falk, M. Schröder, T. Trent | | 2019 |
| Analysis | Examination of short term changes in near-surface/PBL water vapour within GOSAT timeline. Consistency of MW and SWIR products will be assessed in order to produce a (prototype) global dataset. | T.Trent, M. Schröder | | Fall 2020 |
| Model Assessment/ Evaluation (application) | Use G-VAP gridded TCWV archive in first assessment of UK Earth System Model (UKESM) TCWV. Envisaged study at this time would be focused on extreme TCWV events present in the model. | T. Trent | | Fall 2020 |

At a teleconference in summer 2018 it was agreed to communicate details of a region of interest among activity leaders once a team has defined such a region. Further note that each activity is asked to also assess uncertainty estimates when provided with the product and to analyse differences and their significance observed between satellite data records and products from reanalysis when feasible.

All team leaders are encouraged to publish achieved results in peer-reviewed literature prior to the release of the WCRP report in late 2020/early 2021. The co-chairs plan to set up a special issue in a peer-reviewed, open access journal. In order to get potentially cited in IPCC AR6, publications need to be submitted by December 2019 and accepted by September 2020.

## 6 Common approaches

The analysis is carried out in SI units for TCWV ($kg/m^2$), specific humidity (g/kg) and UTH (%). Spatial averaging within G-VAP avoids intermediate totals. When collocated to "reference" data records, nearest neighbours within certain collocation criteria are searched to allow for a collocation impact analysis.

The assessment inter-compares the satellite data records and compares such records with in-situ and ground-based observations in order to assess their quality (uncertainty, homogeneity and

long-term stability). The quality assessment will be carried out in terms of bias, root mean square difference, each in absolute and relative units, probability density function comparison and change in bias over time. Because sampling differences among the various satellite data records impact the result, the analysis is refined using bins such as day/night, annual cycle, latitude, and clear-sky/all-sky.

In case the satellite data record and the "reference" data record contain uncertainty estimates, the comparison is carried out following Immler et al. (2010). Ideally this includes biases caused by differences in sampling (e.g., clear-sky bias).

All teams are asked to apply the terminology defined in the Guide to the Expression of Uncertainties in Measurements (GUM, 2008; a GUM-based summary is available at http://www.fiduceo.eu/vocabulary) when characterising the quality of the water vapour data records. In case terms are used differently or other terms are used these need to be clearly defined.

## 7 Priorities

A timely accomplishment of G-VAP is needed to cope with the rate at which satellite water vapour products are modified or newly generated. Following GDAP needs[2], a time frame of 3 years is anticipated for this. This together with funding constrains gives reason to assign priorities to the data records and activities. These priorities are deduced from the G-VAP scope:

- Characterisation of satellite data records with temporal coverage of approximately more than ten years through inter-comparison and comparison to ground-based and in-situ observations with focus on stability,
- Identification of physical reasons for observed inconsistencies,
- Information of users on G-VAP results.

High priorities are assigned to satellite data records with long-term (>25 years) temporal coverage and which include water vapour profiles and to the assessment of stability and quality in distinct regional features.

Concerning ground-based and in-situ data records which can be used for evaluation, high priorities are assigned to data records with long-term temporal coverage and documented quality, in particular long-term stability and which also include both profiles and total columns.

## 8 Expected outcome

The main output from G-VAP will be

- Report on assessment results with focus on guidance for GEWEX and information for the user community, in particular the climate analysis and application community.
- Updated information data base on data records considered within G-VAP.
- Updated G-VAP data archive (Schröder et al., 2018).

[2] http://due.esrin.esa.int/meetings/meetings247PRE.php

- Feedback and recommendations to data record PIs and agencies.

Depending on results, outcomes of G-VAP will be submitted to peer-reviewed journals. It is envisaged to publish results first and then condense information from publication in the final report.

## 9 Time line

It is the overall goal to publish results from G-VAP activities by 2020. Consequently, the WCRP report on G-VAP will be submitted in late 2020/early 2021.

It is foreseen to conduct G-VAP workshops every about 1.5 years and to carry out half-yearly teleconferences.

## 10 Governance, communication and participation

GEWEX nominated the following co-chairs:

- Marc Schröder, DWD,
- Helene Brogniez, UVSQ,
- S.-p. Ho, NOAA.

The co-chairs have institutional support and accepted the nomination.

The co-chairs organise teleconferences and workshops, promote G-VAP and its results, organise outreach and communication, and support acquisition of additional funding. The co-chairs supervise G-VAP, report to GDAP and jointly draft the final report.

The co-chairs are jointly responsible to organise and coordinate the assessment, to define and evaluate the scientific and technical activities, and to summarise results and conclusions/recommendations in reports and the scientific literature. Decision making is the responsibility of the co-chairs but decisions will be based on consensus.

The co-chairs report back to GDAP. Workshops are carried out to discuss recent findings, to further refine the plan and to draft and consolidate the assessment reports. The co-chairs organise the workshops and additional teleconferences.

Communication will be based on email exchange, and the webpage is the main portal to inform the G-VAP community and the public on activities and results. G-VAP activities will be organised and executed in (small) teams. The teams will carry out telecons or meetings when feasible, organised by the activity leader. The science activities will primarily be defined at G-VAP workshops in exchange with GDAP. However, they can also be introduced at any time via email to the co-chairs. It was emphasised that, though the support to G-VAP is on voluntary basis, such activities are understood as commitments. All activities are and will be included in the assessment plan, which is publicly available at the G-VAP webpage.

The status of the activities will be presented and discussed at the G-VAP workshops. Reports on (grouped) activity results will be published via the web and will be included in the assessment report. The leaders of the activities are responsible for organising and presenting the status at G-VAP meetings and teleconferences. Activity reports need to be sent to the co-chairs by the leaders of the activities in time for overall assessment report drafting no later than Q3 2020. It is the responsibility of the activity leaders to inform PIs on report contents. Figure 1 shows an overview of G-VAP, grouped activities and relevant links.

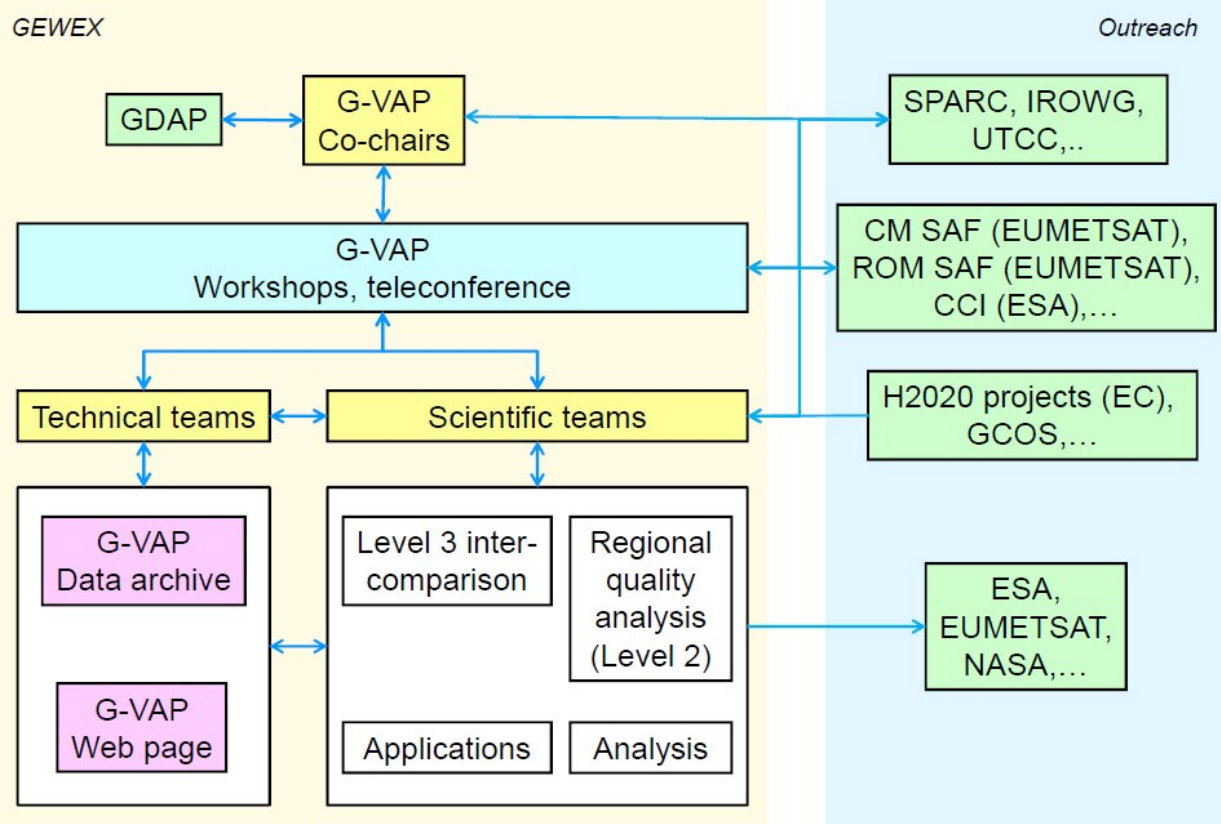


**Figure 1: Overview of G-VAP.**

When the activities exhibit spurious quality for certain data records, the corresponding PIs will be contacted by the activity leaders for clarification. If issues in Level-1 data seem to be present, space agencies will be contacted by activity leaders.

Participation to G-VAP is voluntary - any participant can withdraw their data records partly or entirely from the assessment at any time. In this case, the concerned data will be removed from the databases and not further be used in any respect.

The following support is needed from data record PIs for participation in G-VAP:

- Provision of technical specifications and relevant documentation,
- Agreement on data policy,
- Upload of data record,

- Provision of one or multiple data import tools (readers),
- Support on data utilisation and interpretation of results.

Envolved PIs will be informed on G-VAP results.

## 11 Candidate lists and the G-VAP data archive

The G-VAP webpage contains fairly comprehensive overview tables of candidate satellite and reanalysis (http://gewex-vap.org/?page_id=309) as well as ground-based and in-situ data records (http://gewex-vap.org/?page_id=386). These tables are continuously updated.
The term "candidate" indicates that these data records are potentially valuable for consideration in G-VAP. However, not all of them might actually be analysed or utilised for comparison within G-VAP.

Data records which meet the requirements defined in section 2 will in principle be considered and if downloaded/uploaded comprise the G-VAP data archive. This archive contains a subset of the data records that are listed at the homepage. The G-VAP data archive version 1 is doi-referenced (Schröder et al., 2017) and the overview publication on the archive also includes abstracts per data record (Schröder et al., 2018).

With the continuation of G-VAP this archive will be updated. The updated release will include newly generated data records, data records which have not been considered yet and new versions of data records of the current G-VAP data archive. It is planned to keep the overall format and technical specifications of the archive, with one important change: In order to minimise the gap between last year covered by data records of the archive and release date and in order to enhance applicability, the data records will no longer be provided for a common period but for their individual temporal coverage (adapted from Schröder et al., 2018).

## 12 Data policy

All data records participating to the G-VAP activities (e.g. satellite and non-satellite observations, reanalyses) as well as data products derived within G-VAP (e.g. merged and co-located data products) shall freely be available to all G-VAP participants under the following conditions (adapted from http://fluxnet.ornl.gov/):

- Users should inform the appropriate PIs and G-VAP co-chairs of download, anticipated use and publication plans.
- If the PIs feel that they should be acknowledged or offered participation as authors, an agreement on such matters shall be reached prior to publishing and/or use of the data for publication.
- We encourage users to check with PIs as to the availability of updated data.
- We encourage users to provide information to the PIs and to the G-VAP co-chairs if suspect values are found in the data.

After the end of the G-VAP activities, the data products derived within G-VAP (i.e., re-gridded and reformatted data, netCDF files with common meta data for the G-VAP data archive as in Schröder et al., 2018) will freely be made available to the public.

## 13 References

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## Appendix

Recommendations from G-VAP's first phase (WCRP, 2017).

- CGMS, Space Agencies: Improve upon current satellite profiling capabilities with goals of providing high precision and long term stability, with sufficient vertical resolution, complete, unbiased global sampling and independency of models.
- CGMS, Space Agencies: Dedicated validation archive for all water vapour sensors, also including ship based RS.
- CGMS, WMO, GRUAN: Aim at the sustained generation and development of a stable, bias corrected multi-station radiosonde archive including reprocessing of historical data.
- CGMS, WMO: Achieve consistency among reference observing systems and sustain corresponding services.
- WMO, GCOS: Oppose and balance user, scientific and product requirements with focus on climate analysis.
- Space Agencies: Need for continental high quality satellite data records.
- Space Agencies: Need for inter-calibrated radiance/brightness temperature data records and homogeneously reprocessed instantaneous satellite data records.
- Space Agencies, GEWEX: Provide water vapour transport product in order to analyse atmospheric dynamics and to evaluate the constancy of relative humidity.
- Space Agencies, PIs: Develop and provide PDF based climatology of satellite-based radio-occultation data.
- Space Agencies, PIs: Provide averaging kernels, a priori state vectors and associated error covariance matrices together with the release of profile products.
- Space Agencies, PIs, G-VAP: Estimate and provide uncertainty information and assess uncertainty estimates, also as function of total amounts and other dependent parameters.
- Space Agencies, PIs, G-VAP: Improve stability of long-term data records and (re)assess improvement in stability.
- Space Agencies, PIs: Provide information on input to data records such as precise start and stop dates and number of observations as function of time and input data type.
- GEWEX, SPARC, G-VAP, WAVAS: Joint WAVAS and G-VAP analysis of data records covering the upper troposphere and lower stratosphere using the same methodology.
- GRUAN: Include station over tropical land.
- GRUAN: Reassess the uncertainty estimates at large humidity values.
- GRUAN: Provide estimates of the correlation uncertainty between levels or guidance on how to compute it from information already available (ideally the covariance matrix of uncertainties is provided).
- GEWEX: Continuous support to G-VAP, beyond acceptance of first report.
- G-VAP, Space Agencies, PIs: Enhance quality analysis of profile data records over open ocean, in particular over high pressure areas/subsidence areas and stratus.
- G-VAP, Space Agencies, PIs: Analyse differences between observations under all-sky as well as cloudy and clear sky conditions.
- G-VAP: Reassess the TTD of humidity profile data by taking into account the vertical resolution and sensitivity and the characteristics of the PDF at certain levels/layers.
- G-VAP: Assess the joint effect of orbital drift, clear sky sampling/bias and the diurnal

cycle of clouds on biases and how this might change with climate change.

- G-VAP supports the ITSC-20 recommendation on the reinstallation of the TPW ARM station.
- G-VAP supports the ITSC-20 initiative to collect SRF data in common format at a common location.
- G-VAP supports the concluding remarks from the Joint workshop on uncertainties at 183 GHz.